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Energy audit study of three rice husk fired boilers at Indian Acrylics Ltd.

Prepared for **Indian Acrylics Ltd, Harkishanpura, Sangrur (Punjab)**

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Acknowledgement

TERI places on record its sincere thanks to The Indian Acrylics Limited (IAL), Harkishanpura, Sangrur, Punjab for entrusting us with the assignment of energy audit of three rice husk fired boilers. The contribution and advice of Mr S P S Bakshi, Senior General Manager (Projects) and Mr R K Sharma, General Manager (Works) during the entire course of the project was very valuable and helped the project team to shape the study. Our sincere thanks are also due to Mr Vineet Aggarwal, Manager (Utilities) for providing his support and expert comments to the project team.

We greatly acknowledge the support of entire engineering and maintenance staff of boilers in completing the field measurements during energy audit.

Executive summary

The main report contains detailed analysis and recommendations emerging from the study of the plant. A summary of the major recommendations has been given in the following sections.

FBC Boilers

- The plant has three rice husk fired retrofitted boilers. The efficiency of boiler#1, #2 and #3 is worked out to be 80.15%, 81.65% and 80.06% respectively.
- All the boilers are operating with higher excess air. It is beneficial to maintain the excess air level at 40% in the boilers which will improve boiler's efficiency by 1-1.5%.
  - The savings in this regard would be Rs 8.9 lacs per annum. The total investment of Rs. 18 lac for all the boilers would be paid in two years. Other than this plant will also save electricity, as the load on FD/ID will also be reduced.
- Regarding the super heater's tubes failures in radiation zone, it is suggested to increase the flow through these tubes by reducing the numbers of superheater's tubes as it is stated to be overdesigned. Alternatively, a radiation shield may be provided to protect the tube portion which gets punctured occasionally due to radiation.

Pumps and fans

- A study was conducted to assess the performance of the pumps and fans under the prevailing operating conditions.
- The efficiency of the boiler feed pump at 41% loading was worked out to be 49.6% which was fairly good.
- Option of installing a variable speed AC drive (VFD) instead of conventional throttling was explored. It was found that control valves are required to be in the circuit even after installation of VFD.

- A combination of both valve regulations as well as speed control would be used to regulate the flow. Thus, the achievable saving would be reduced to some extent.
- The control valves can be eliminated from the feed lines if all the boilers produce and feed at 225°C steam to a common header, and only a small amount of steam (STPH) is taken from this header to the superheater in one of the boilers for giving steam at 425°C.
- In absence of the pump characteristics and system resistance curve, it is not possible to comment on the feasibility of using VFD for this application.

▪ The efficiency of FD fans is worked out to be in the range of 70 to 84%, which is fairly good.

▪ The efficiency of ID fans is found to be slightly low (in the range of 53 to 72%).

▪ Replacing existing configuration of ID fans in series with a single energy efficient fan was explored.
  - It was found that there would be a maximum efficiency gain of around 6% compared to the existing operation.
  - The plant shall have to install a VFD for regulating the speed of the ID fan to maintain the balanced draft inside the boiler. Therefore, the total cost of the system would be Rs 12.00 lacs. The estimated annual savings are to the tune of 47,700 kWh (assuming 8760 hrs/year) for one boiler amounting to Rs 1.6 lacs (@ Rs 3.4 per kWh) can be achieved yielding a simple payback period of 7.5 years.

▪ In case the plant decides against installing a VFD in the new system, less efficient flow control techniques like dampers, etc. shall have to be provided. This would reduce the saving of the system.

▪ The measured gas flow across both the ID fans indicates a leakage of about 1000 Nm^3/hr between main ID fan and bag filter ID fan. By arresting the leakages in the circuit, an energy saving of about 6834 kWh (Rs 23,000) per annum per boiler can be achieved.

1 Introduction

Comprehensive energy audit of three rice husk fired boilers of M/s Indian Acrylics Limited (IAL) at Harkishanpura, Sangrur, Punjab was carried out by Tata Energy Research Institute (TERI), New Delhi, to study the operating efficiency of steam generating boilers and to identify the energy saving possibilities. TERI team visited the plant in May-June, 2002 to undertake measurements and for collection of data. Discussions were also held with the utility personnel to accomplish the task in a meaningful manner.

The plant has three rice husk fired Atmospheric Fluidised Bed Combustion (AFBC) boilers. These are retrofitted boilers (converted from oil fired shell type boilers) which is done by M/s Cheema Boilers. These boilers are supplying superheated steam to the plant at about 18 Kg/cm^2 (g) and at 225°C & 425°C. The steam demand of the plant is about 35 TPH.

This report presents the findings of the energy audit study of thermal efficiency of three rice husk fired boilers carried out by TERI. The study was aimed at assessing the operational performance of the boilers by evaluating thermal efficiency at different operating conditions and suggests energy conservation measures for improving the operating efficiency. The efficiencies of the boilers are worked out by indirect method on the basis of boiler trials conducted during the field visit. Sensitivity analysis is also carried for these boilers to understand the change in boiler efficiency with respect to the variation in critical parameters. This study also includes the performance of FD/ID fans, feed water pump and their motors.

The savings available by operating the boilers with optimum levels and corresponding to the actual rice husk consumption have also been evaluated. The objectives of the study and methodology adopted are detailed in the following sections.

2 Boilers

2.1 Boilers details

There are three rice husk fired atmospheric fluidised bed combustion (AFBC) boilers in the plant. Earlier these boilers were oil fired shell boilers and later converted in to AFBC boilers by M/s Cheema Boilers. Each boiler is equipped with super heaters, identical economiser, air preheater, two forced draft (FD) and two induced draft (ID) fans. Boiler#1 operates with one superheater whereas the Boiler#2 & #3 with two superheaters. Plant has the requirement of 5 ton of steam at 425°C which is catered by boiler#2 and #3 through both the superheaters. Rest of the steam is generated at about 225°C. The capacity of each boiler is 15 tph at 18 kg/cm ^{2} (g). Out of the three boilers, normally two operate at a time. During the energy audit, all the three boilers were in operation.

There are two plenum chambers separated by a partition wall in the combustion zone of each boiler. The boilers have three-step capacity control i.e. 0%, 50% and 100% of the rated capacity. Whenever boilers are operated with one bed, one FD fan is kept closed. There is no control of fans outputs during one and two bed operation as it may lead to bed disturbance as stated by the plant personnel. All the FD and ID fans are having variable speed drives to control the draft but these are hardly operated. The total air from FD fan is divided in two streams-1) the primary air which is fed at the bottom of the bed, and 2) the secondary air which is fed above the bed. The ratio of secondary to primary air is 1:3. The maximum steam demand of the plant is stated to be about 35 TPH. For any demand above 30TPH, boiler #1 is kept on variable load. Large and very frequent fluctuations were observed in steam demand of the plant. These lead to unsteady operation of the boilers. The boilers are also equipped with volumetric and mass flow meters for the steam. Mass flowmeter was not functioning properly during the study period.

2.1.1 Fuel

The fuel used is rice husk. There are 2 rice husk feeders in each boiler, arranged in the front wall, which supply the fuel to furnace beds through screw feeder. Boilers are designed for over bed firing and fuel is sprayed on the bed with the help of a stocker. Sample of rice husk, bottom ash and fly ash, from all the boilers were collected during the study and the analysis is given below. Table 2.1.1a shows the rice husk analysis and the Table 2.1.1b shows the bed ash analysis. These parameters are used on "as fired" basis for calculating the performances of the boilers.

Table 2.1.1a Rice husk analysis

Parameter	Boiler 1	Boiler 2	Boiler 3
Proximate analysis (wet basis)			
Moisture(%)	8.57	8.52	9 82
Ash (%)	11 58	11.66	10.80
Volatile matter (%)	63 35	63.76	62.46
Fixed carbon (%)	16 50	16 06	16.92
Ultimate analysis (dry basis)			
Carbon (%)	39 6	39 3	39 8
Hydrogen (%)	6 16	6.15	6.17
Nitrogen (%)	0.23	0 23	0.24
Sulphur (%)	0.01	0.01	0.01
Ash (%)	12.66	12.75	11.98
Oxygen (%)	41 34	41 57	41.81
GCV (Kcal/kg)	4100	4050	4130

Table 2.1.1b Ash analysis

Parameter	Boiler 1	Boiler 2	Boiler 3
Carbon content in bed ash (%)	3.30	1.18	1.40
Carbon content in fly ash (%) (at bag filters)	12.5	12.42	18.0

2.1.2 Feed water system

The condensate from various process equipments is collected in hot-well at high temperature. The condensate and make-up water go to de-aerator. The temperature of water in de-aerator is raised to about 105±5°C. From deaerator, feedwater goes to the individual economiser where it is heated up to 130±10°C and goes to the respective boiler. Condensate return is reported to be 70%.

2.1.3 Blow down

Intermittent blow down is practised in three boilers. It is performed on the basis of boiler water analysis provided by the plant laboratory. The individual blowdown pipe is drained near the shed of the respective boiler. As per existing practices, blowdown in three boilers is manually carried out when boiler water

reaches to the TDS level between 1000-1500 ppm based on the actual water analysis.

2.1.4 Methodology

The operational performance of a boiler can be determined by working out its thermal efficiency. The thermal efficiency can be evaluated by either direct or indirect method. In direct method, the boiler efficiency is computed as a ratio of the net enthalpy of steam generated and the heat input to the boiler. The reliability and accuracy of rice husk flow, steam flow measurement are very critical for the direct method, which can be quite misleading sometimes. However, this method does not provide information on associated heat losses of the boiler. In indirect method, the various heat losses associated with the boiler are first computed and the thermal efficiency is determined as the difference of hundred and the sum of all the heat losses. Hence, indirect method is more accurate and revealing and, therefore, chosen to calculate the thermal efficiency. The ASME indirect method was adopted here to evaluate the boiler efficiency, as it helps in identifying avoidable heat loss components.

It was decided to carry out trials of individual boiler at two different steady loads. The load fluctuations on boilers were so frequent and wide that it was not possible to perform the trials with boilers on auto mode, as all the three boilers are inter linked and the any change in one boiler affects the whole boiler system. Therefore, this exercise was performed with boilers on manual modes. Effort were made to measure the parameters at the steady load of boilers but it was not possible in all the trials, because the variations could not be eliminated even in manual mode of operation.

During boiler's manual mode of operation, uniform flow of rice husk is maintained (depending upon the steam demand), but its automatic mode makes proportionate change in husk flow because of any steam load change in the plant. There is no control on the air flow for combustion though all the FD/ID fans are equipped with variable speed drives. The following measurements were taken to analyse the performance of the boiler at any fixed load.

- Rice husk feeding rate
- Rice husk, flyash and bottom ash samples
- Feedwater and blowdown samples
- Flue gases analysis (after boilers, economisers and air preheaters) for O_2, CO and flue gas temperature

- Structural temperature of boilers
- Ambient conditions (dry bulb and wet bulb temperature)
- Temperature (before and after economiser) of water and flue gases
- Temperature (before and after air preheater) of combustion air and flue gases
- Volumetric steam flow rate

The following control panel parameters were also noted at the regular intervals of 20-30 minutes to observe the consistency of controllers, steadiness of operating parameter without formation of clinker, differences in combustion at different conditions to know the affects on flue gas, combustion patterns and the overall performance of the boiler.

1. Husk Feeder %age
2. Steam pressure (kg/ cm^2)
3. Steam temperature (^oC)
4. Steam flow ('000 m^3/ hr)
5. Inlet air temperature (^oC) for FD 1 & FD 2
6. Feed Water temperature (^oC) at after economiser & before economiser
7. ID fan draft (-mm wc)
8. FD 1 (mm wc) for primary draft & secondary draft
9. FD 2 (mm wc) for primary draft & secondary draft

2.1.5 Boiler efficiency

Boilers efficiencies are calculated by calculating following losses first and then subtracting them from 100. The heat losses from the boilers include

- Dry gas loss which is a function of excess air, the flue gas composition and the corresponding gas temperature at air heater outlet. This loss was established by taking flue gas analysis after the boiler, economiser and after air heater.
- Losses due to combustion of hydrogen and moisture which depends on % H_2 and moisture in fuel; moisture in air, etc; excess air and exit gas temperature.
- Unburnt carbon losses which depends on the unburnt in bottom and flyash.
- Sensible heat loss in bottom and fly ash
- Radiation losses

2.1.6 Basic input data for computing boiler efficiency

The important parameters used for the performance evaluation of the boilers by indirect method, are given below.

1. Oxygen percentage in flue gas
2. Carbon monoxide level in flue gas
3. Flue gas temperature
4. Drum pressure
5. Feed water temperature
6. Steam flow rate
7. Fuel consumption rate
8. Temperature of boiler surfaces
9. Analysis of fuel and ash
10. Ambient conditions (temperature & relative humidity)

2.2 Observations, analyses and recommendations

Boiler trials were carried out at the load 12-14 TPH and efforts were to stabilise the boiler at this condition to take data at three points viz. after boiler, after economiser and after air heater at same condition. But, due to practical difficulties, it couldn't happen in all the cases. In many cases, load changed before the recording of parameters at second sample port, in succession. Minimum two sets of parameters were taken for each boiler, using various portable instruments and these are averaged to arrive at most appropriate readings. These sets of data recorded during the field visit are given in Annexure2.1. Wherever it is not possible to take measurements by using the portable instruments, panel readings are used for the calculations. For calculating the husk consumption, weighed quantity of rice husk was dumped before husk feeding systems of each boilers and the time taken to consume this amount was recorded. The summary of performance of all the three boilers are evaluated by indirect method and mentioned in the Table 2.2 along with few important parameters. Details are given in Annexure 2.2.

Table 2.2 Performance of boilers

Parameters	*Boiler #1*	*Boiler #2*	*Boiler #3*
Measurements & observation			
Oxygen content in flue gas* (%)	9 5	7.5	9.0
Excess air level*(%)	79	53	71
CO level (%)*	0.21	0.06	0.1
Outlet flue gas temperature (°C)	125	124	125
Ambient conditions			
Dry bulb temperature - 33°C			
Wet bulb temperature - 31°C			

Parameters	Boiler #1	Boiler #2	Boiler #3
Heat balance			
Dry flue gas loss (%)	4.94	4.23	4.74
Loss due to CO in flue gas (%)	1.04	0.27	0.49
Loss due to moisture in air (%)	0.24	0.21	0.23
Loss due to hydrogen and moisture (%)	9.71	9 81	9 88
Loss due to unburnt in bottom ash (%)	0 21	0.08	0.08
Loss due to unburnt in flyash (%)	2.34	2 59	3.17
Loss due to sensible heat in bottom ash (%)	0.11	0.11	0.10
Loss due to sensible heat in fly ash (%)	0 05	0.05	0.05
Structural loss (%)	1.2	1 0	1.2
Total heat losses (%)	19 85	18.35	19.94
Boiler efficiency (%)	80.15	81 65	80.06

* after boiler

It is clear from the above table that biggest loss is the heat loss due to hydrogen and moisture in the fuel followed by dry flue gases loss. These losses are discussed in the detail below.

2.2.1 Loss due to hydrogen and moisture in fuel

This is the biggest loss in all the boilers and depends upon the moisture and hydrogen content of the husk and flue gas exit temperature. The moisture and hydrogen content of the fuel is fixed and, therefore, the only controlling factor is the exit flue gas temperature. This loss due to hydrogen and moisture in fuel is worked out to be in a range of 9.7% to 9.9%. Since flue gas temperature is already at its lowest and therefore, further lowering will tend to condensation of the moisture in bag filters and in chimney. Therefore this loss will exist and is beyond the control as the possibility of reducing it is ruled out. However, seasonal variation in moisture and hydrogen content can vary this loss.

The variation of boilers' efficiency with variation in moisture in rice husk are shown in figures 2.2.1a to 2.2.1c. It is clear from these figures that there is not much impact of moisture on the boiler's efficiency. There is only 1% variation when the moisture content varies from 6% to 12% in the husk, keeping other parameters constant.

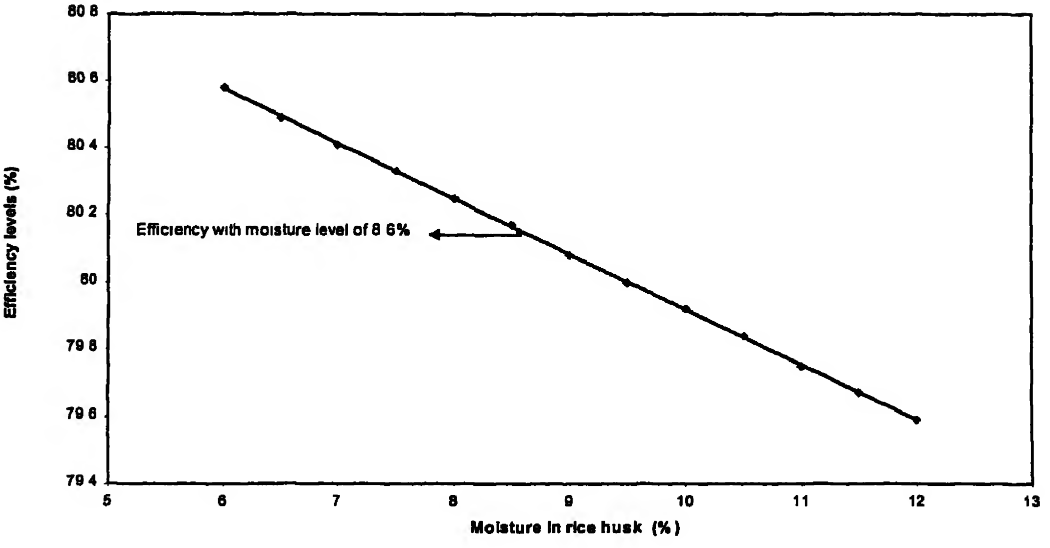


Figure 2.2.1a Variation in efficiency with change in %moisture in rise husk for boiler#1

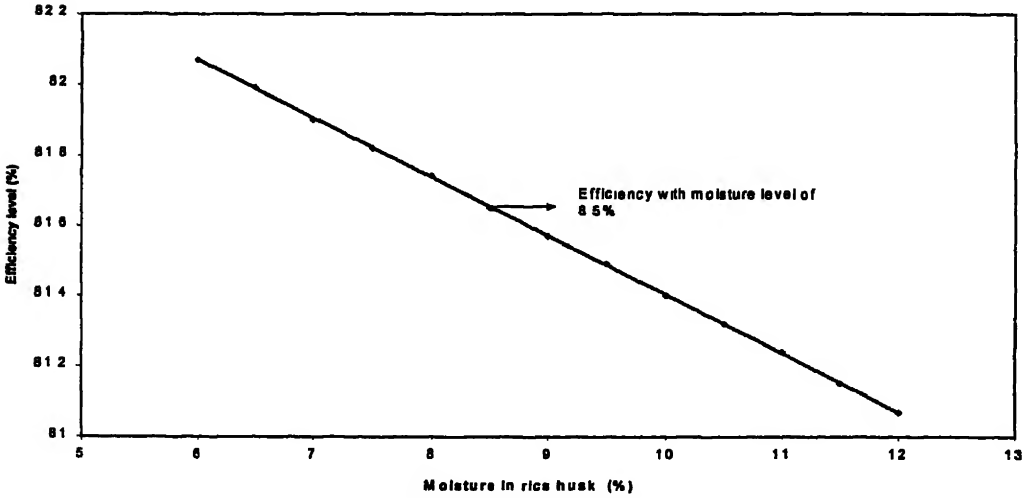


Figure 2.2.1b Variation in Efficiency with change in %moisture in rise husk for boiler#2

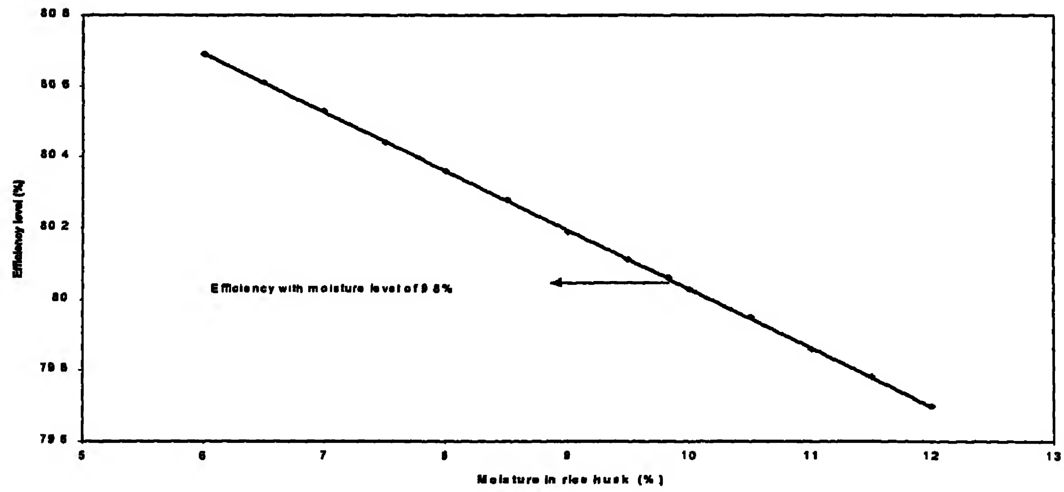


Figure 2.2.1c Variation in Efficiency with change in %moisture in rise husk for boiler#3

2.2.2 *Dry flue gas loss*

The dry flue gas loss mainly depends on two factors namely a) excess air level and b) flue gas temperature at the exit. These two factors are discussed in detail below.

2.2.2.1 Excess air level

Excess air is one of the important parameter in determination of boiler's performance. Every fuel needs a specified quantity of stoichiometric air for its combustion. In actual practice, since, mixing of fuel with air is never perfect, a certain amount of excess air is always needed to complete the combustion and ensure the release of entire heat contained in the fuel. Too much of air results in excessive heat loss as the surplus air does not take part in combustion but carries away heat to the atmosphere from the boiler furnace. Besides, surplus air lowers the furnace temperature and thereby the heat transfers rate & total heat transfer and overall efficiency.

Likewise, if the excess air is too less than the optimum quantity, combustion would be incomplete resulting in the formation of gases like carbon monoxide etc, in the flue gas. The maximum permissible limit for CO is 0.1%. Above this, loss due to CO formation is higher than the benefit availed on account of lower excess air level.

As is clear from the Table 2.2, average excess air level (monitored) of all the boilers is above the reasonable limit (i.e. 35-40%). The actual excess air levels measured were varying in a range of 52%-117% for boiler#1, 24%-99% for boiler#2 and 41%-194% for boiler#3 respectively as given in Annexure 2.3. The excess air in the plant is varying with boiler's load. It is high at lower load and vice versa. It was also observed that excess air control is not exercised by varying the FD/ID fan speeds at different loads and that is why that excess air variations were observed in a wide stretch. The efficiency sensitivities with oxygen levels in flue gas for all the boilers are plotted as figure 2.2.2.1a to 2.2.2.1c.

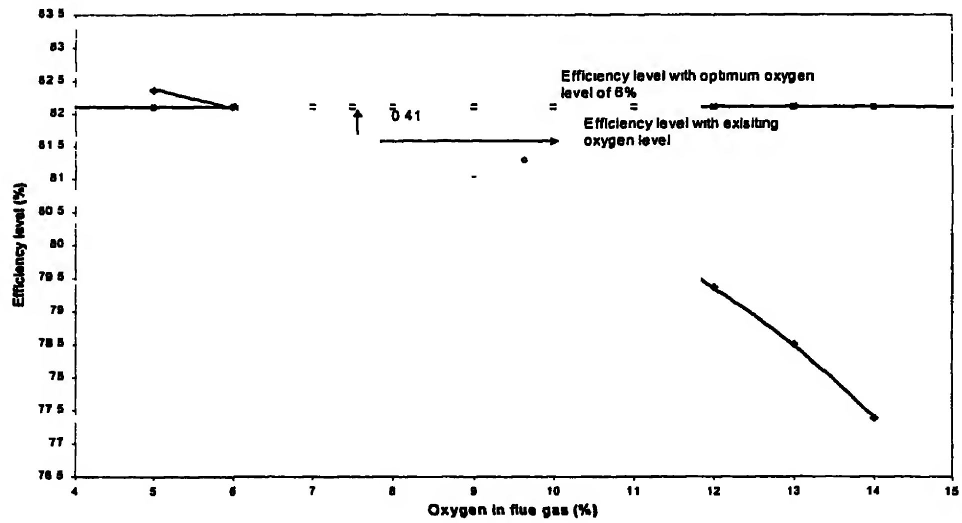


Figure 2.2.2.1a Variation in Efficiency with change in %O2 in flue gas for boiler#1

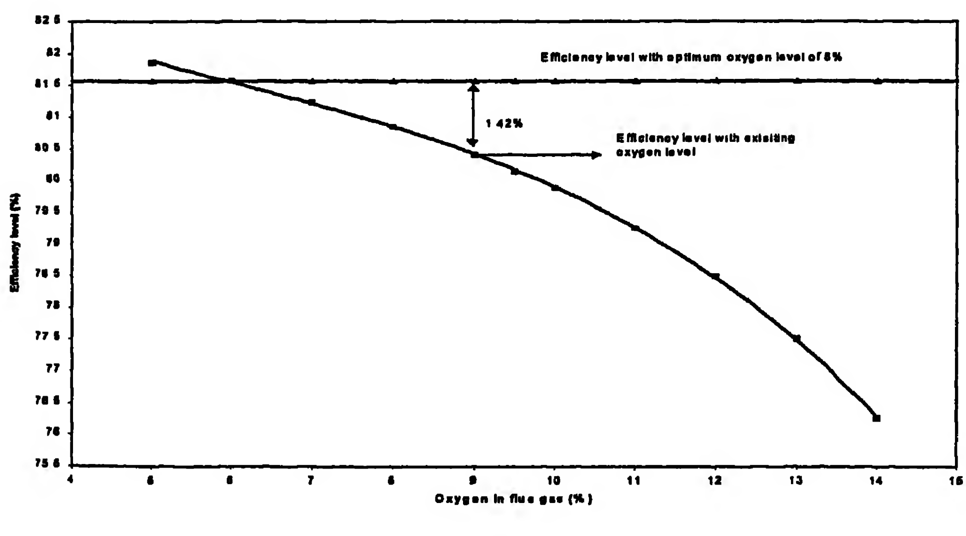


Figure 2.2.2.1b Variation in Efficiency with change in %O2 in flue gas for boiler#2

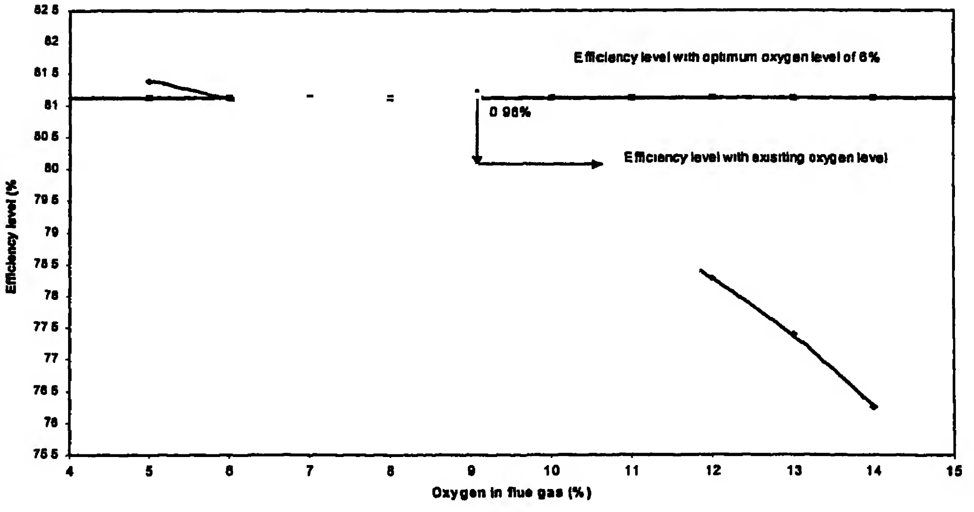


Figure 2.2.2.1c Variation in Efficiency with change in %O2 in flue gas for boiler#3

Optimum efficiency is calculated at 6% (40% excess air) oxygen level in the flue gas whereas all other factors are kept constant. Departure from the optimum efficiency is also shown in the figures which is the difference between optimum efficiency line and the actual efficiency curve. It increases with the increase in percentage oxygen levels and is one of the reasons of lower boiler efficiencies. It is, therefore, recommended to operate the boilers at about 6% oxygen level (~40% excess air) in the flue gas.

If problem in fluidisation is faced at some point of time due to excess air reduction, quantity of primary air may be increased by reducing the secondary. The improvement in efficiency by implementing this suggestion is shown in the Table 2.2.2.1 below.

Table 2.2.2.1 Improvement in efficiency

Boiler	Current average oxygen level in flue gas (%)	Efficiency with current oxygen levels (%)	Efficiency with 6% oxygen levels (%)
Boiler#1	9.5	80.15	81.57
Boiler#2	7.5	81.65	82 1
Boiler#3	9	80.06	81 12

It is desired to install automatic excess air controllers which will keep the excess air level in a desirable limit by controlling the fuel and air flow. The total savings by excess air reduction would be about Rs. 8.9 lac per annum.

Reduction of excess air was also demonstrated during the study by reducing the airflow from FD fans (by controlling the motor speed) and a savings of about 5 kW was also observed. This saving would be in addition to the fuel savings.

The cost of installing the excess air controllers would be paidback in about 2 years. Detailed calculation is given in Annexure 2.3. The name and address of the supplier is given below.

M/s Techmark Engineers & Consultants
K1/28, Ground Floor
Chittaranjan Park
New Delhi - 110 019
Phone: 011-6236974,6438349/6216003
Fax: 011-6217979,6236974
Email: techmark@bol.net.in

Some other reputed suppliers of oxygen analysers/control systems are (1) Fisher-Rosemount, (2) ABB Instruments and (3) Forbes Marshell.

2.2.2.2 Flue gas temperature

Flue gas temperature is another major contributor to the dry flue gas loss and also has the impact on other losses. The flue gas temperature after air preheater in all the boilers was measured to be about 125°C which is okay if it is not leading to condensation in bag filters and chimney during normal operation

2.2.3 Loss due to unburnt in fly ash

This loss is calculated to be 2.34% for boiler#1, 2.59% for boiler#2 and 3.17% for boiler#3 and is due to the unburnt particles in the fly ash which are trapped before the bag filters. The unburnt carbon percent in the fly ash samples, collected at the bag filters of each boiler, are 12.5%, 12.4% and 18% respectively for boiler#1, #2 and #3. Rice husk being a low bulk density material, escapes without burning completely if the air velocity in boiler is excessively high. It is anticipated that after reducing the excess air, through air controllers, these losses are likely to come down.

2.2.4 Structural loss

The structural loss in the boilers are calculated in a range of 1 to 1.2%, which is within the limit. However, few spots like inspection doors and windows need special attention as the temperature is too high there.

2.2.5 Heat loss due to CO

The carbon monoxide (CO) level in the flue gas indicates the health of combustion. It should be minimum to achieve a better combustion efficiency. The loss due to CO in the boiler#1 is significant because of high carbon monoxide content in flue gas. In other two boilers it is less or equal to 0.5 %. The efficiency variations with respect to CO are shown in the figures 2.2.5a to 2.2.5c. The basis CO level for each boiler is the average of all the sets of reading taken for the respective boilers. The average CO value is less or equal to 0.1% for all the boilers except boiler#1, which is the recommended value. Higher CO levels were also observed while taking the sets of readings as shown in Annexure 2.3 at higher boiler loads between 14-16 M^3/hr. Since air quantity supplied to the boilers remains same at higher loads (higher fuel consumption) excess air quantity gets reduced which is inadequate for this type of fuel. Due to this CO level increases. Also, load fluctuation is another reasons for this in the boiler because of inadequate air fuel mixing.

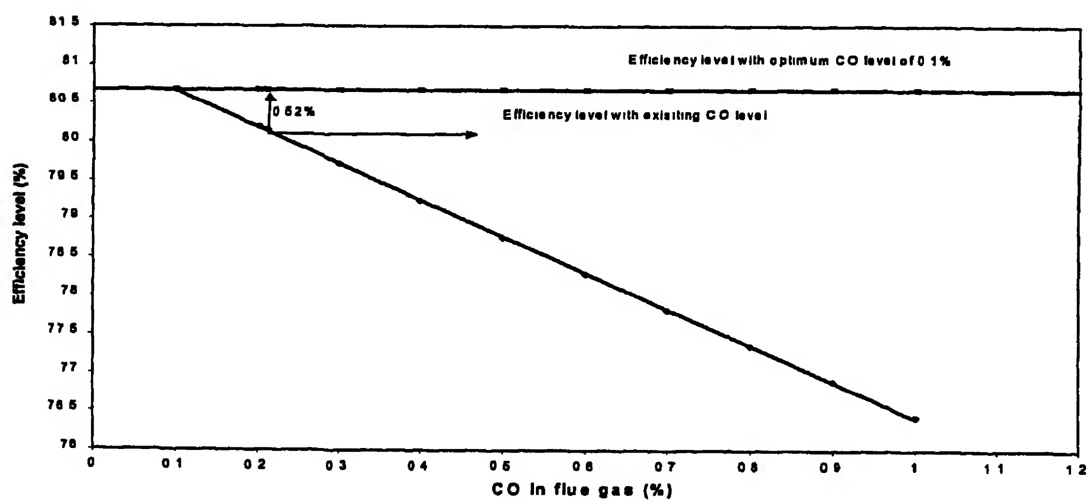


Figure 2.2.5a Variation in Efficiency with change in %CO in flue gas for boiler#1

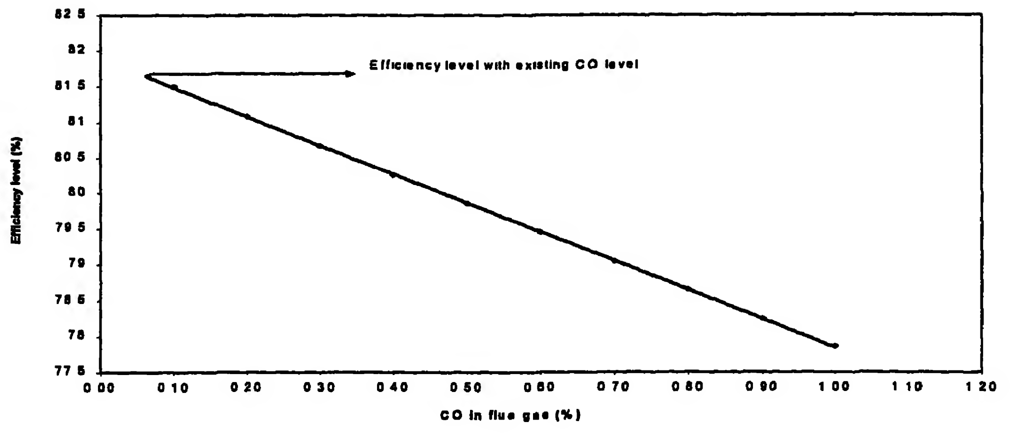


Figure 2.2.5b Variation in Efficiency with change in %CO in flue gas for boiler#2

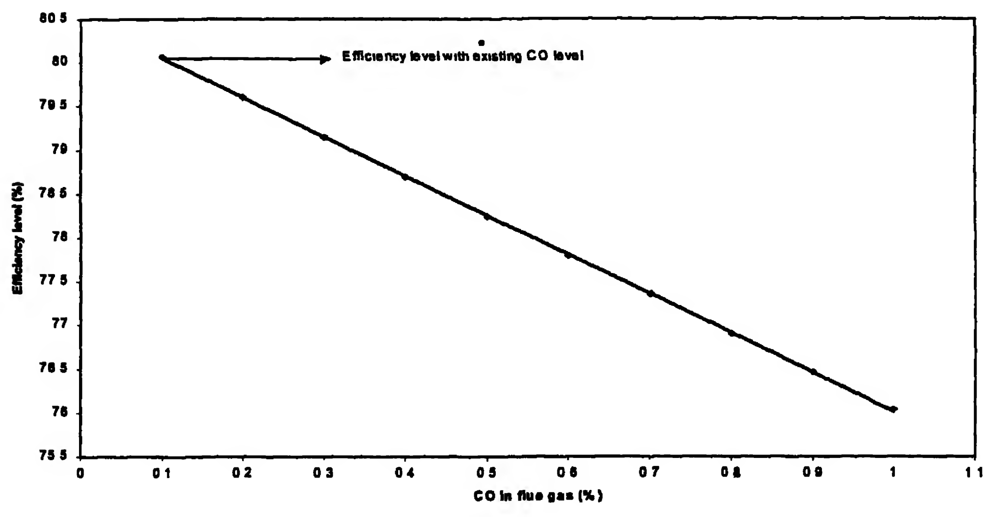


Figure 2.2.5c Variation in Efficiency with change in %CO in flue gas for boiler#3

2.2.6 *Loss due to Moisture in air*

This loss is because of moisture content in air, which depends on the relative humidity and the ambient temperature. The controllable factors, on which this loss depends, are excess air level and flue gas temperature. Presently, this loss is calculated to be in a range of 0.21 to 0.24% in boilers and will get reduced to

0.19% after excess air reduction. The savings due to this is incorporated in savings due to excess air reduction.

2.2.7 *Loss due to unburnt in bottom ash*

This loss is varies from 0.08% in boiler#2 and #3 to 0.21 in boiler#1 and depends on the unburnt content of the bottom ash. Bottom ash samples were collected during the plant visit and sent to the SIIR laboratory for determination of combustible, which is tested to be 3.3%, 1.8% and 1.4% for boiler#1, #2 and #3 respectively.

2.2.8 *Sensible heat loss in ash*

This heat loss is due sensible heat carried away in bottom ash and flyash and depends on the bottom ash disposal and flue gas temperature. These losses are about 0.11% and 0.05% respectively for bottom and fly ash.

2.3 Tubes burn out in radiation zone

During the discussion it has been reported that there is frequent failure of superheater's tube in the radiation zone. It has, also, been told that the super heater is designed for 7.5 TPH and presently operating at 5 TPH. The tubes normally fail at lower U-bend in the furnace radiation zone. It was evolved during the discussion that flow in superheater tubes is less as only 5 TPH of superheated steam is drawn in place of 7.5 TPH as designed and due to this more heat is received by tube than what it transfers to steam. It is, therefore, suggested to reduce the number of tubes from the superheater to increase the steam flow in the remaining tubes which will absorb all the heat radiation falling on the tube and avoid the formation of hot spots leading to tube failures. Alternatively, a radiation shield (piece of half annular tube of larger diameter) may be provided to protect the super heater tube portion which gets damaged occasionally due to radiation.

3 Pumps and fans

3.1 Pumps

The plant has two boiler-feed pumps of capacity 55 m^3/hr each. Out of two pumps, one pump runs continuously to meet the water requirements of all the three boilers while the other one is kept as standby. As the combined steam load of all the three boilers varies with time, the flow rate of the pump (and hence the loading of pump motor) changes with total steam demand. The specifications of the pump are given in Table 3.1.

Table 3.1 Specification of the pump

Equipment	*Capacity (m^3/hr)*	*Head (mlc)*	*Rated power (kW)*	*RPM*
Boiler feed pump	55	265	75	2965

To evaluate the performance of the pump, the flow-rate was measured using portable ultra-sonic flow meter and discharge pressure was noted down from the pressure gauge installed on delivery side of the pump. The suction pressure of the pump has been calculated based on the water height above the pump inlet. The performance of pump has been evaluated using the following method.

3.1.1 *Evaluation of pump performance*

The efficiency of a pump is defined as the ratio of useful power output to the power input to the pump shaft.

$$Pump\ efficiency = \frac{Power\ output}{Power\ input}$$

The power output of a pump is the energy delivered to the fluid by the pump (figure 3.1.1). It was calculated from the formula

$P_{out} = wQ\Delta H$

P_{out} = Power in Watts
w = Sp. wt. of fluid, N/m^3

Q = Flow-rate, m^3/s
ΔH = Total dynamic head, m

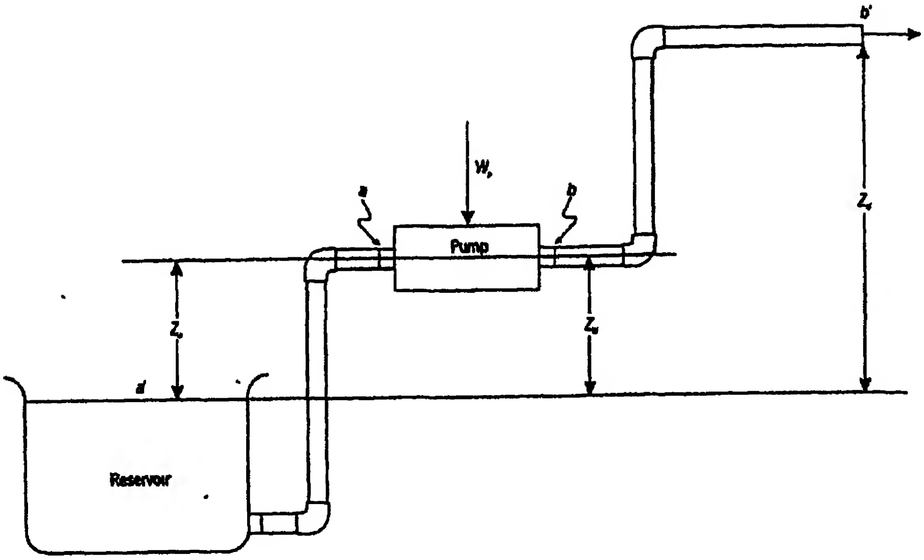


Figure 3.1.1 Pump flow system

The flow-rate was obtained by installing portable flow meter on the delivery pipe and the total dynamic head was calculated by the following formula.

$\Delta H = (H_b - H_a)$.
Where
H_b= total discharge head $P_b/\rho + gZ_b/g_c + V^2{}_b/2g_c$
H_a= total suction head $P_a/\rho + gZ_a/g_c + V^2{}_a/2g_c$
ΔH = total dynamic head
P_b= discharge pressure
P_a= suction pressure
V_b= discharge velocity
V_a= suction velocity
Z_b= height of the discharge
Z_a= height of suction
ρ = density, kg/m^3

Since *A* and *B* are at the same reference height (Z_b and Z_a) this expression simplifies to

$$\Delta H = \left(\frac{P_b}{\rho} - \frac{P_a}{\rho}\right) + \left(\frac{V^2{}_b}{2g_c} - \frac{V_a{}^2}{2g_c}\right)$$

Where, the entrance velocity is V_a and the exit velocity is V_b. In the present case, inlet and outlet pipe were almost same, V_a and V_b will be equal, then the

$$\Delta H = \frac{P_b - P_a}{\rho}$$

The actual power taken by the motor was measured with the help of a highly accurate digital power multi-meter and the power input to the pump shaft was obtained after considering the efficiency of the motor.

3.1.2 Observations, analysis and findings

Based on the measurements and data collected, the efficiency of the pump was evaluated. The detailed calculation of the efficiency of the pump is given in Annexure 3.1. Summary of calculations is tabulated below (Table 3.1.2).

Table 3.1.2 Pump efficiency

				Measured parameters		
Application	Rated power (kW)	Power drawn (kW)	% motor loading	Flow (m^3/hr)	Head (m water column)	Efficiency (%)
Boiler feed pump	75	47.4	58	23	342	49.6

At the time of measurement, the pump was supplying water to two boilers (boiler number 2 and 3) and the third boiler (boiler 1) was not on load. The efficiency of the pump at 41 % of the load (23 m^3/hr) is found to be 49.6 %, which is fairly good.

3.1.3 Installation of Variable Frequency Drive (VFD) for boiler feed pump

The variation of the total steam load on the boilers is reflected in varying water requirements of the system. Accordingly the pumping requirement of the BFP varies from 23m^3/hr to 34m^3/hr. In percentage terms, this variation corresponds to about 20 percent of the rated capacity of the pump. Presently this flow variation is being done by regulating the control valves installed for individual boilers.

Since this form of regulation is not the most efficient way of regulating the flow, other energy efficient flow regulating techniques like installing a VFD was

explored. Using a VFD to regulate the water flow through speed control would also result in reduction of pressure generated by the pump (the head varies as the square of the speed). Normally the reduction in pressure due to speed control gets compensated to some extent by keeping the control valve 100 % open after installation of VFD. Thus, elimination of throttling losses by way of variable speed is the main key to saving energy. But in present case, the control valves are required to be in the circuit even after installation of VFD because of varying flow requirements of individual boilers at the same time. For most effective use of VFD each valves should be fully open and flow controlling should be done by reducing the speed. In the present case this is not possible. However, if same load can be maintained on all the three boilers, then a variable speed drive can be used with boiler feed pump. A combination of both valve regulations as well as speed control would be used to regulate the flow therefore the achievable saving would be reduced to some extent. In absence of the pump characteristics and system resistance curve it is not possible to comment whether reduced pressure due to speed reduction would be able to meet the system requirement or not. Therefore, it is not possible to comment on the feasibility of using VFD for this application.

If all the three boilers produce steam at the same rate (tph) at 225°C, and if this steam is put into a common header and STPH, steam is withdrawn from this header for superheating from 225 to 425°C to one of the boilers, it is possible to have one boiler feed pump with VFD and no control valves in the feed lines. This arrangement would be most economical solution. The complete solution cannot be worked out as the system losses in the feed lines and pump characteristics are not known.

3.2 Fans

A study was conducted to assess the performance of Inducted draft (ID) and Forced Draft (FD) fans of boilers under the prevailing operating conditions. Each boiler is provided with two FD fans for handling combustion air. The FD fans are connected in parallel and each fan supplies air to one plenum of the boiler. There are two ID fans connected to each boiler for handling flue gases after combustion. The location of various fans is shown section 3.2.3. As can be seen from the figure, the ID fans are connected in series. The first ID fan is used to maintain the balance draft inside the boiler while the second one is for overcoming the pressure drop across the bag filter. The important design parameters of the fans are given in Table 3.2.

Table 3.2 Details of fans

Fans	*Quantity (m³/min)*	*Total static pressure (mmWG)*	*Motor rating (kW)*	*Rpm*
FD fan-1	200	400	22	1440
FD fan-2	200	400	22	1440
ID fan main (for boiler balanced draft)	750	250	55	720
ID fan for bag house	750	150	37	630

3.2.1 Observations, Analysis and Findings

The quantity of flue gas/air handled by each fan was determined by measuring air velocity, temperature and duct area at the suction/delivery side of the fans by using velocity manometer and thermocouple. The static pressure at the suction and delivery sides of fans was measured using digital pressure manometer. The measured parameters for FD and ID fans are given in Table 3.2.1a and 3.2.1b respectively.

Table 3.2.1a Measured parameters of FD fans

Measured parameters	*Unit*	*Boiler No. 1*		*Boiler No 2*		*Boiler No 3*	
		FD-1	*FD-2*	*FD-1*	*FD-2*	*FD-1*	*FD-2*
Static pressure at the delivery side	MmWG	365	368	386	377	371	375
Duct area	M²	0.2	0.2	0.2	0.2	0.2	0.2
Velocity	M/s	15.1	14.4	13.6	12 6	13.45	13.7
Speed	%	90	90	90	90	90	90
Damper opening	%	100	100	100	100	100	100
Measured power	KW	15.6	14.4	13.6	15.6	15.6	15.6

Table 3.2.1b Measured parameters of ID fans

Measured parameters	*Unit*	*Boiler No. 1*		*Boiler No. 2*		*Boiler No. 3*	
		ID Main	*ID Bag Filer*	*ID Main*	*ID Bag Filer*	*ID Main*	*ID Bag Filter*
Static pressure (suction side)	MmWG	-238	-161	-227	-123	-181	-120
Static pressure (delivery side)	MmWG	5	6	35	17	38	6
Duct area	M²	0.75	0.75	0.75	0.75	0.75	0.75
Velocity	M/s	11.6	12.6	11.6	12.1	13.7	14.1
Speed	%	93	94	92	100	93	90
Damper opening	%	100	100	100	100	100	100
Measured power	KW	31 5	27.6	40.8	26.1	39.3	25.5

3.2.2 *Methodology adopted to evaluate fan performance*

For example, let us consider ID Main fan for boiler no-2

1. Static pressure, velocity and temperature are measured at the sample points for each fan using pressure manometer, pitot tube, velocity manometer, and thermocouple.

   The measured parameters for ID main fan of boiler no-2 are:

Suction side	=	-227
Delivery side	=	35
Temperature	=	124 °C
Duct area	=	0.75 m^2

2. The density of air or gas at fan inlet (sample point) can be known from NTP values (1.29 kg/Nm^3 or 1.295 kg/Nm^3) by temperature and pressure correction.

   Density of flue gas - 1.295 kg/Nm^3

Density of gas at sample point can be known by the formula:

$$\rho_2 = \rho_1 \times \frac{T_1}{T_2} \times \frac{P_2}{P_1}$$

ρ	=	Density in kg/m^3
P	=	Pressure in mm WG
T	=	Temperature in Kelvin

Suffix –1	=	Represents parameters at NTP
ρ_1	=	1.295 kg/ Nm^3
P_1	=	1 bar = 10330 mm WG
T_1	=	0 °C = 273 K
Suffix –2	=	Represents measured parameters at sample point

$$P_2 = 1.295 \times \frac{273}{(273+124)} \times \frac{(10330-227)}{10330}$$

∴ Density at sample point, P_2 = 0.8709 kg/m^3

From the height of manometer fluid displacement and density at sample point, velocity can be obtained from the formula

$$V = K\sqrt{\frac{2GHD_m}{D_s}}$$

Where,

V	=	Air velocity in m/sec
K	=	Pitot caliberation constant = 0.831
G	=	Gravitational acceleration equal to 9.81 m/sec^2
H	=	Height of manometer fluid displacement in meter
D_m	=	Density of manometer fluid equal to 1592 kg/m^3 for carbon tetra chloride
D_s	=	Stack-gas density in kg/m^3

$$V = 0.831\sqrt{\frac{2\times 9.81\times 0.0055\times 1592}{0.8709}}$$

V = 11.67 m/sec

By knowing the area of sample point (duct diameter), the quantify of flow (Q in m^3/sec) can be known by:

Q	=	A x V
A	=	Area (m^2)
V	=	Velocity (m/sec)
Q	=	0.75 x 11.67
	=	8.753 m^3/sec
	=	31511.43 m^3/h (525.19 m^3/min)

Since fans operate at different conditions, in order to compare them, it is essential to know the flow in Nm^3/h

The quantity of flow at NTP (Nm^3/h) can by known by

$$= Q\times\frac{Density\ of\ gas\ at\ fan\ inlet\ (samplepoint)}{Density of\ gas at\ NTP}$$

$$= 31511.43 * \frac{0.87094}{1.295}$$

$$= 21192.71 \text{ Nm}^3/\text{h}$$

Theoretical power can be calculated from the formula,

$$kW = \frac{Q \times TP \times g}{3600 x 1000}$$

Q = flow in m^3/h

TP = Total static pressure in mmWG

g = Acceleration due to gravity in m/sec^2

Q & TP are measured parameters

$$kW = \frac{31511 \times [35-(-227)] \times 9.81}{3600 X 1000}$$

$$Actual\,or\,measured\,power = \frac{Theoretical\,power}{\eta_{fan} \times \eta_{motor}}$$

= 22.495 kW

$$\eta_{fan} = \frac{Theoretical\,power}{Actual\,or\,measured\,power x \eta_{motor}}$$

$$= \frac{22.495 x 100}{40.8 x 0.93}$$

= 59.28%

Based on the above methodology, mechanical efficiency of the fans is calculated as given in Table 3.2.2a and 3.2.2b.

It can be seen from the table that the efficiency of the FD fans is in the range of 70 to 84%, which is fairly good. The efficiency of ID fans is slightly low in the range of 53 to 72%.

Table 3.2.2a Efficiency of FD fans

Measured parameters	Units	Boiler No.1		Boiler No.2		Boiler Nol 3	
		FD-1	FD-2	FD-1	FD-2	FD-1	FD-2
Density	kg/m^3	1.191	1.191	1.193	1.192	1 192	1 192
Temperature	°C	306	306	306	306	306	306
Static pressure suction side	MmWG	0	0	0	0	0	0
Static pressure delivery side	mmWG	365	368	386	377	371	375
Duct Area	m^2	0.2	0.2	0.2	0.2	0.2	0.2
Velocity	m/s	15.1	14.4	13.6	12.6	13.4	13.7
Quantity	m^3/min	181	173	163	151	161	165
Quantity	m^3/h	10916	10386	9792	9086	9684	9921

Measured parameters	Units	Boiler No 1		Boiler No.2		Boiler Nol 3	
		FD-1	FD-2	FD-1	FD-2	FD-1	FD-2
Quantity	Nm³/h	10083	9596	9067	8407	8950	9173
Speed	%	90	90	90	90	90	90
Damper opening	%	100	100	100	100	100	100
Theoretical power total	kW	10.85	10.41	10.29	9.33	9.79	10.13
Measured power	kW	15.6	14 4	13.6	15.6	15.6	15.6
Rated capacity of motors	kW	22	22	22	22	22	22
Efficiency of motor		0.91	0.9	0 9	0 91	0 91	0.91
% motor loading	%	64.5	58.9	55.6	64.5	64.5	64 5
Fan efficiency static	%	76.4	80.3	84.1	65.7	68 9	71 4

Table 3.2.2b Efficiency of ID fans

Measured parameters	Boiler No 1		Boiler No.2		Boiler No.3	
	ID Main	Bag Filter	ID Main	Bag Filter	ID Main	Bag Filter
Density	0.869	0 876	0.870	0 879	0.861	0 867
Temperature	397	397	397	397	403	403
Static pressure suction side	-238	-161	-227	-123	-181	-120
Static pressure delivery side	5	6	35	17	38	6
Duct Area	0.75	0.75	0 75	0.75	0 75	0.75
Velocity	11.6	12.6	11.6	12.1	13 7	14.1
Quantity	525	569	525	545	616	634
Quantity	31528	34145	31509	32724	36990	38089
Quantity	21179	23114	21192	22248	24618	25502
Speed	93	94	92	100	93	90
Damper opening	100	100	100	100	100	100
Theoretical power total	20.87	15.53	22 49	12.48	22.07	13.02
Measured power	31.5	27.6	40.8	26.1	39.3	25.5
Rated capacity of motors	55	37	55	37	55	37
Efficiency of motor	0.92	0 915	0.93	0.91	0.92	0 91
% motor loading	52.6	68.2	68 9	64.1	65.7	62.7
Fan efficiency static	72.0	61.5	59 2	52.5	61.0	56.3

3.2.3 Recommendations

3.2.3.1 Replacing series connected ID fans with a single fan

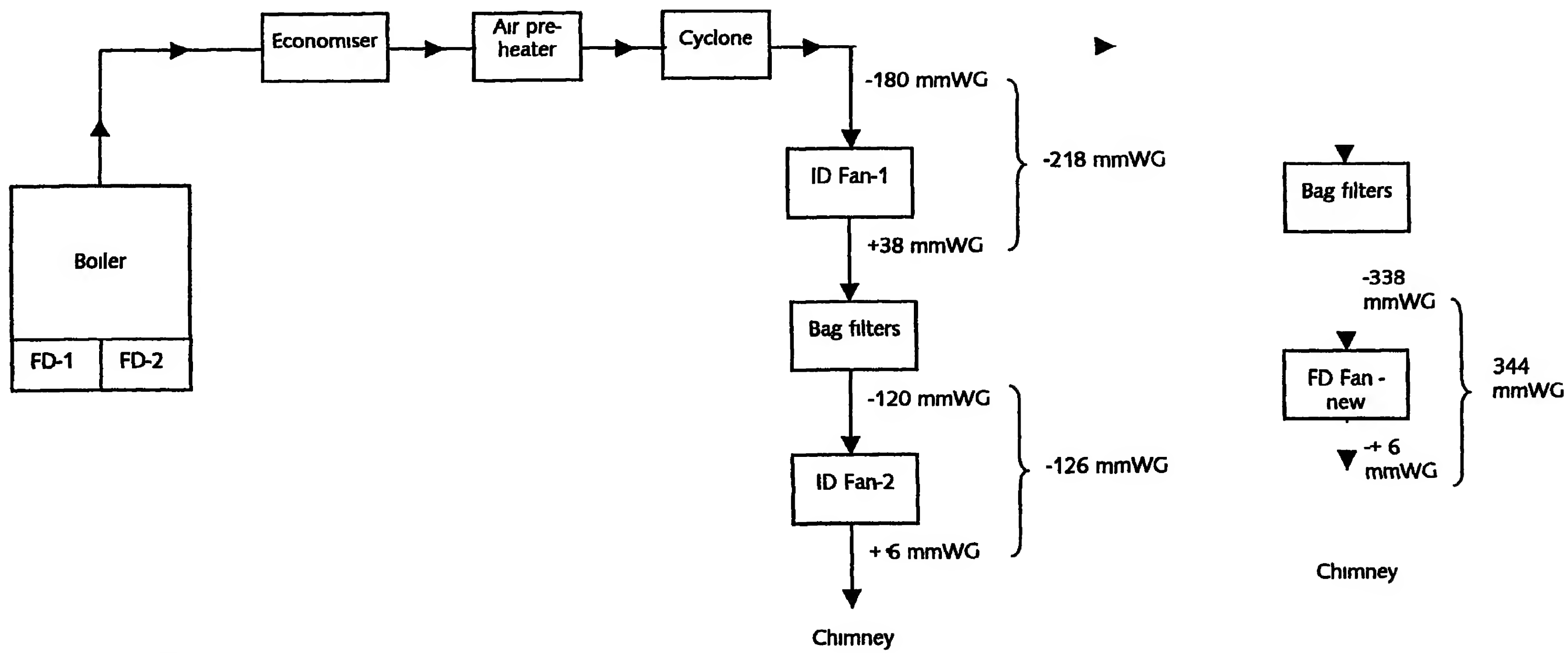
The operating efficiency of the existing ID fans is in the range of 53 - 72 %. Replacing the existing configuration of series fans with a single energy efficient fan was explored as shown in Figure 3.2.3. It was seen that there would a maximum efficiency gain of around 6% compared to the existing operation. Annexure 3.2 gives detailed quotation of M/s Alstom. The estimated annual saving are to the tune of 47,700 kWh (assuming 8760 hours per year) for one boiler amounting to Rs 1.60 lacs (@ Rs.3.40 per kWh) can be achieved. The plant shall have to install a VFD for regulating the speed of the ID fan to maintain the balanced draft inside the boiler. Therefore the total cost of the

system would primarily include the cost of the fan, cost of the motor and the cost of the inverter. This would amount to Rs 12 lacs. The invested amount shall be paid back in more than 7.5 years, which seems to be on the higher side. Moreover the existing fans and the inverter drive shall have no utility in the plant.

In case the plant decides against installing a VFD in the new system, less efficient flow control techniques like dampers etc shall have to be provided. This would reduce the saving of the system.

3.2.3.2 Arresting air infiltration in flue gas

The measured gas flow across both the ID fans indicates a leakage of about 1,000 Nm^3/hr between main ID fan and ID fan for bag filter. By arresting the leakages in the circuit, considerable amount of energy can be saved. This leakage accounts for 6834 kWh p.a. for one boiler. The details are given in Annexure 3.3.



Existing

Proposed

- no problem operation-wise with ID fan new
- ID fan new with better efficiency only will reduce power consumption

Figure 3.2.3 Single line diagram showing replacement of two ID fans with a single fan

Annexure 2.1

Table A.2.3.1 Operating parameter for trial of Boiler 1

Sl. No	*Sampling point*	*Constituent*	*Set 1*	*Set 2*	*Set 3*
1	After boiler drum	O2 (%)	11.6	7.4	4 4
2		CO (ppm)	1348	2794	160
3		FGT(0C)	187 8	195	226
4	After economiser	O2 (%)		5.1	3.7
5		CO (ppm)		1198	482
6		FGT(0C)		181.2	174
7	After air preheater	O2 (%)		5.1	7.2
8		CO (ppm)		2800	82
9		FGT(0C)		124.7	119.4

Table A.2.3.2 Operating parameter for trial of Boiler 2

Sl. No	*Sampling point*	*Constituent*	*Set 1*	*Set 2*
1	After boiler drum	O2 (%)	4.24	10.73
2		CO (ppm)	609	276
3		FGT(0C)	222.1	214
4	After economiser	O2 (%)	4.6	--
5		CO (ppm)	1002	--
6		FGT(0C)	179.7	--
7	After air preheater	O2 (%)	5.2	--
8		CO (ppm)	1155	--
9		FGT(0C)	124.6	--

Table A.2.3.3 Operating parameter for trial of Boiler 3

Sl. No	*Sampling point*	*Constituent*	*Set 1*	*Set 2*	*Set 3*	*Set 4*	*Set 5*
1	After boiler drum	O2 (%)	14.1	8	7.6	6 3	9
2		CO (ppm)	475	3454	1390	3792	228
3		FGT(0C)	206	194.6	201.3	203.7	203
4	After economiser	O2 (%)		5 3	5.55	3.4	9
5		CO (ppm)		5891	4267	8931	357
6		FGT(0C)		185	194.6	181.3	181
7	After air preheater	O2 (%)	11.4	8.9	5.12	2.8	7.9
8		CO (ppm)	281	360	4738	6918	292
9		FGT(0C)	134	128	133.3	106.2	123.4

Boiler efficiency

Parameters (average)	*Boiler#1*	*Boiler#2*	*Boiler#3*
Oxygen in flue gas (%)	9.5	7.49	9.0
Carbon monoxide in flue gas (%)	0.21	0.0635	0.101
Maximum Carbon dioxide s (%)	19.72	19.76	19.78
Carbon dioxide in flue gas (%)	10.63	12.65	11.21
Excess air (%)	79	53	71
Flue gas temperature (°C)	125	124	125
Theoretical air requirement (kg/kg of fuel)	4.46	4.42	4.41
N2 in flue gas (kg/kg of fuel)	79.66	79.80	79.69
Dry flue gas quantity (kg/kg of fuel)	8.38	7.15	7.97
Nitrogen quantity in flue gas (kg/kg of fuel)	6.21	5.27	5.90
Inlet air quantity (kg/kg of fuel)	8.08	6.85	7.68
Heat released by burning 1 kg of carbon (kcal/kg)	8084	8084	8084
Mean specific heat of flue gas (KJ/kg C)	1.0077	1.0059	1.0071
Moisture calculation			
Air			
DBT (°C)	33	33	33
WBT (°C)	31	31	31
Humidity ratio (kg/kg of dry air)	0.0282	0.0282	0.0282
Moisture content of air (kg/kg of air)	0.0274	0.0274	0.0274
GCV of rice husk(as fired)	3749	3705	3724
Fuel			
Moisture in fuel (kg per kg of fuel)	0.0857	0.0852	0.0982
Hydrogen in fuel (kg per kg of fuel)	0.0563	0.06	0.0556
Total moisture in flue gas (kg per kg of fuel)	0.811	0.776	0.806
Specific heat of moisture (Kcal/kg-°C)	0.4498	0.4498	0.4498

Parameters (average)	*Boiler#1*	*Boiler#2*	*Boiler#3*
Losses			
Dry flue gas loss	4.94	4.23	4.74
Heat loss due to CO in flue gas	1.04	0.27	0.49
Heat loss due to moisture in air	0.24	0.21	0.23
Heat loss due to moisture and hydrogen in the fuel	9.71	9.81	9.88
Heat loss due to unburnt in bottom ash	0.21	0.08	0.08
Heat loss due to unburnt in fly ash	2.34	2.59	3.17
Sensible heat loss in bottom ash	0.11	0.11	0.10
Sensible heat loss in fly ash	0.05	0.05	0.05
Radiation heat loss	1.20	1.00	1.20
Total Losses	**19.85**	**18.35**	**19.94**
Thermal Efficiency	**80.15**	**81.65**	**80.06**

Savings due to reduction in excess air

	Boiler#1	*Boiler#2*	*Boiler#3*
Existing			
Average oxygen (%)	9.5	7.49	9
Efficiency (%)	80.15	81.65	80.06
Fuel consumption (MT/hr)	2.4	2.88	3.35
Improved			
Oxygen (%)	6	6	6
Efficiency (%)	81 57	82.1	81.12
Fuel savings (MT/hr)	0.042	0.016	0.044
Assumed working hours per annum	5500	5500	5500
Fuel savings per annum (MT)	230	87	241
Cost of husk (Rs./Ton)	1600	1600	1600
Monitory savings per annum (Rs. Lac)	3.68	1.39	3.85
Investment			
Cost of air controller (Rs. Lac)	6	6	6
Simple payback period (years)	1.6	4.3	1.6

Efficiency calculation of boiler feed pump

Flow rate, Q	=	85 GPM = 23.188 m^3/h
Sp. wt. of water, w	=	9.81x1000 N/m^3
Suction head, $P_{s/\rho}$	=	7.5 m
Discharge pressure, P_d	=	35 kg/cm^2 (g)
Discharge head, $P_{d/\rho}$	=	350 m
Total dynamic head, ΔH	=	342.5 m
Power output of the pump	=	Sp. wt.x Q x TDH
	=	21.64 kW
Measure power input to motor	=	47 4 kW
Efficiency of the motor assumed	=	0.92
Power input to pump shaft	=	43.60 kW
Efficiency, E_p	=	Power output/ Power input
	=	49.6 %

Annexure 3.2

ALSTOM

SKG/IED/AFF-Q.

DATED: 25.7.2002

Mr. Kulbhushan Kumar,
Research Associate
Industrial Energy Group
TERI,
Habitat Place,
Lodi Road
New Delhi - 110003

YOUR ENQUIRY FOR CENTRIFUGAL FANS:- ID Fans. - Your Fax dt 19.7 & 20.7.20
A/C-

Dear sirs,

We have pleasure in quoting for the fans against your above enquiry as follows:

ITEM	1	2		
QUANTITY	-	-		
AIR QTY. M^3/Hr.	24000	36000		
ST.PRESSURE (MM WG) at 130°C	410	430		
Corrected S.P at 20°C (Curve condition)	587	618		
MODEL	284/1-1250/SI	284/1-1400/SI		
TYPE OF FAN	SISW - Arr. 1 - backward inclined bladed.			
SPEED(RPM)	1425	1330		
Static efficiency	72.5%	72%.		
BKW at 20°C	53 kw	87.9		
B K W at 130°C	38.5 kw	63.9		
Impeller dia (mm)	1250	1400		
Recommended Motor Rating in K W/Pole	75/4	110/4		
Unit Price of Fan with Motor & Accessories, as follows	Rs. 233254/-	Rs. 327990/-		
ACCESSORIES: Comprising V-belts, Pulleys, belt guard and channel base W/O vibration isolators.				

cont-2

ALSTOM

TERMS 8 CONDITIONS

PRICES Ex Works, Kolkata in unpacked condition.

DISCOUNT Prices quoted are net after taking out discounts

EXCISE DUTY Extra as applicable at the time of supply The current rate is 16%

SALES TAX Sales tax will be extra as applicable ruling on the date of billing The current rate of Central Sales Tax is 10% and against C from the same will be at 4%

DELIVERY The material can be made ready for despatch ex Works.Kol-kata in 6/8 weeks after receipt of firm order with full technical details and advance. In case approval of drawing and data is involved , the delivery period will be reckoned from the date of receipt of clearance of such documents

PAYMENT 20% advance with the order and the balance against proforma bill on readiness of the material before despatch.

DISCREPANCY/ DAMAGE . Discrepancies/damages, if any, must be reported within 21 days of receipt of material, failing which it will not be possible to attend/rectify the same free of cost.

GUARANTEE. Our equipment will be guaranteed for 18 months from the date of supply or 12 months from the date of commissioning, whichever is earlier. against any manufacturing defect or faulty workmanship.

VALIDITY This offer is valid upto 30.9.2002

NOTE 1) Inspection, if involved, shall be restricted to physical/dimensional check and run test For witness of Routine Test 5% extra is chargeable and for witness of Performance Test extra charges will be advised depending on the works involvement, type and size of the fans.

2) In case of cancellation of the order after 7 days of placement, a cancellation charge of 25% of the order value will be payable.

Yours faithfylly,
For ALSTOM Limited,

(S.K.GUPTA)
ROTATING MACHINES DIVISION

Arresting air infiltration in flue gas

Flow of ID main fan = 31511 m^3/hr

Flow of bag filter ID fan = 32744 m^3/hr

Infiltration of air = 1233 m^3/hr

Corresponding power loss = $$\frac{Q \times TP \times g}{3600 x 1000 \times \eta_{fan} \times \eta_{motor}}$$

Q = flow in m^3/h (1233 m^3/hr)

TP = Total static pressure in mmWG (140)

g = Acceleration due to gravity in m/sec^2 (9.81)

$$= \frac{1233 \times 140 \times 9.81}{3600 x 1000 \times \eta_{fan} \times \eta_{motor}}$$

(Assuming efficiency of motor as 91%, the calculated efficiency of fan from the measures values comes to 53%)

= 0.97 kWh

Assuming 80% of this leakage can be arrested, power saving will be

= 0.97 x 0.8

= 0.78 kWh

Annual energy loss (@ 24 hrs/day and 365 days per year)

= 6834 kWh/year

By arresting the leakages in the circuit, the annual cost savings that can be obtained (@ Rs 3.4 kWh)

= 6834 x 3.4

Annual cost savings = Rs 23,000

Investment required = Marginal

Simple payback period= Immediate